

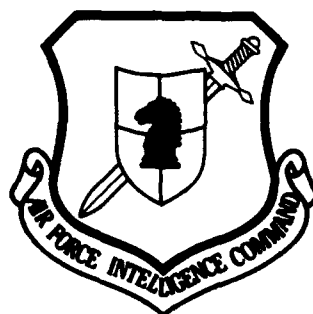
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INVESTIGATION OF MESOSCALE CONVECTIVE
CLOUD CLUSTERS IN SOUTH CHINA

by

Jiang Jixi, Ye Huiming, Chen Meizhen

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FASTC-ID(RS)T-0369-93

3 November 1993

MICROFICHE NR: **93C000627**

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English pages: 22

Source: YINGYONG QIXIANG XUEBAO, Vol. 1, No. 3, August 1990;
pp. 232-241

Country of origin: China

Translated by: Leo Kanner Associates
F33657-88-D-2188

Requester: USAF Environmental Technical Applications Center/
Robert A. Van Veghel

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INVESTIGATION OF MESOSCALE CONVECTIVE CLOUD CLUSTERS IN SOUTH CHINA

By

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(Satellite Meteorology Center, State
Meteorology Administration)

ABSTRACT:

The statistical characteristics of 176 mesoscale convective cloud clusters in South China, which are classified into three types in terms of their size, are analysed based on the short interval GMS images and conventional data during April—October, 1980—1988. Two composite model charts are presented for their formation and development, and two typical cases are studied. Some conclusions can be drawn as follows: (1) Mesoscale convective cloud cluster is a major member of severe mesoscale convective systems in South China. (2) The convergences of wind and moisture fields in the surface layer and orographic forcing are the trigger mechanism for the genesis of cloud clusters. (3) Low-level jet and monsoon cloud swell are the most important factors for the development of cloud clusters.

I. Introduction

A mesoscale cloud cluster is a principal member of mesoscale intensive convective weather systems in South China; this is a relatively intensive catastrophic system. The occurrence of a mesoscale cloud cluster is abrupt, with rapid and violent buildup, accompanied by abrupt rain gushes, thus forming floods down mountainsides. In some cases, the extent of the catastrophe

may exceed a typhoon. Since the late 1970s, some extensive and penetrating studies on mesoscale cloud clusters were conducted in China and abroad by using short-time interval satellite cloud clusters and radar data with a combination of conventional weather data. Thus, some important features[1,2] of mesoscale cloud clusters were revealed, preliminarily. In Fang Zhongyi's[3] studies on rain gushes in the flood season of the Yangtze River Valley and South China by using satellite cloud maps, he proposed that large-scale cloud forming modes developed from mesoscale cloud clusters. Jiang Jixi et al.[4] also conducted a more detailed analysis on mesoscale alpha-type cloud clusters. The data used in these studies covered a relatively short number of years, relating to a greater scale of cloud clusters with the main emphasis on analyzing examples. This article utilized GMS cloud map data and conventional weather maps of three-hour intervals every day between April and October during the nine years of 1980 through 1988. One hundred seventy six different sizes of mesoscale cloud clusters were investigated and analyzed with respect to their origin, passes, formation and development conditions, as well as the resulting weather. Thus, some significant results were obtained.

II. Activity Characteristics of Mesoscale Convective Cloud Clusters Over South China

1. Horizontal scale, life history, and rainfall features of cloud clusters

The authors divided the investigated 176 cloud clusters into three categories of small, medium, and large; the statistical features are listed in Table 1. From the table, the mesoscale alpha-type cloud clusters and the intermediate-scale cloud clusters predominate. In various cloud clusters, the six-hour rainfall of very few cloud clusters is about double the six-hour rainfall of most cloud clusters. The longest and shortest values of the life history of various types of cloud clusters differ widely from the mean value. The largest value is twice the mean value, and the smallest value is about one-half the mean value. As for the area coverage of these cloud clusters, except for the greater difference between large cloud clusters, the maximum and minimum values of intermediate and small cloud clusters are only 20 to 30 percent lower than the mean value.

TABLE 1. Statistics of Some Features of Mesoscale Cloud Clusters Over South China

类 a	项 b	c 生命史(小时数)			d 面积(平方纬距)			e 6小时雨量(mm)		f 云团数
		平均g	最长h	最短i	平均g	最大j	最小k	大多数l	极少数n	
I	I	10	22	6	2×2	2×3	1×2	20—50	80—130	20
I	II	14	24	6	3×4	4×5	2×4	50—80	90—150	101
II	III	21	54	9	5×7	9×10	4×6	60—120	200—250	55

KEY; a - Type b - Item c - Life history (number of hours) d - Area of coverage (square degrees Lat.)
e - Rainfall in mm, during 6 hours f - Number of cloud clusters
g - Average h - Longest i - Shortest j - Largest k - Smallest l - Most cases
n - Very few cases

2. Origin and passes of cloud clusters

Mainly, the origin of mesoscale cloud clusters over South

China is concentrated in three areas (refer to Fig. 1). One area is in West Guangxi, Northeast Yunnan, and Southeast Guizhou. Out of the 176 cloud clusters mentioned above, nearly one-half originate over this area, which is the main region of origin. Another area is along the borders of West Guangdong and East Guangxi; over these areas is where about one-third of the cloud clusters are located. The origins of few cloud clusters are relatively concentrated over mountainous areas in Northwest Fujian. This distribution of cloud cluster origins reveals that cloud cluster formation not only determines the effect of the weather system, but is also closely related to the relief.

Moving passages of mesoscale cloud clusters differ as to months. In April, with the guidance of the southern branch of the westerlies, the cloud clusters move slightly eastward. In May and June, cloud clusters over the area to the west of 110 deg. E. mainly move southeastward; the cloud clusters over the area to the east of 110 deg. E. generally move slightly eastward. In July through October, the moving passages of cloud clusters are relatively complex with irregularity (diagram omitted).

3. Monthly frequencies and diurnal variation of cloud clusters

The mesoscale cloud clusters are an active mesoscale weather system over South China. In the author's nine-year long investigation, from 1980 through 1988, the average annual number of cloud clusters was 19.5, with an average of 2.8 clusters per month. However, the period April through June of each year

account for about 80% of the total number of cloud clusters occurring throughout the year. In the peak May-June period, the number of cloud clusters is 68% of the total annual number. Therefore, the mesoscale cloud clusters are an important rainfall system in advance of the South China flood season. For the monthly frequency distribution of various cloud cluster types, the small clusters appear mainly from late April to May, mostly in the first 10 days of May (six clusters). In most other months, very few of these clusters appear. For medium and large cloud clusters, most of these appear in May through June, with a rapid drop in July through September. Very few such clusters appear from late September to October.

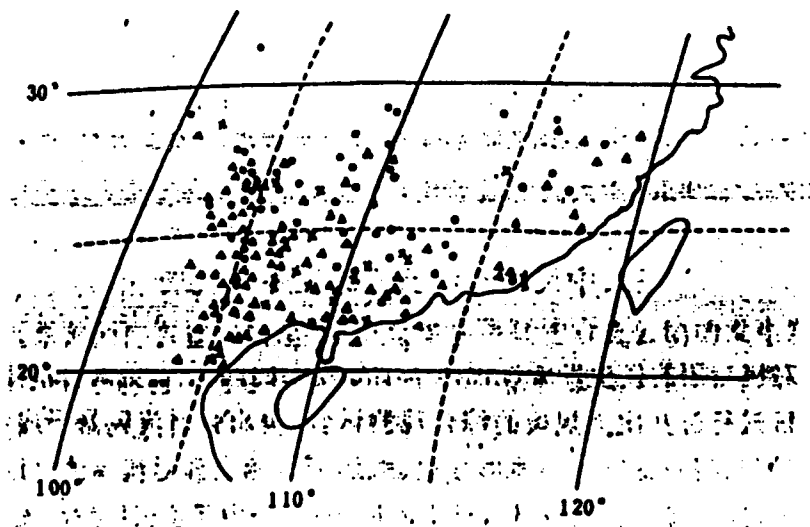


Fig. 1. Distribution of mesoscale cloud cluster origins over South China. (x), Δ , \circ are, respectively, cloud clusters of types I, II, and III

Activities of mesoscale cloud clusters have apparent diurnal variations. The highest frequency of cloud cluster occurrence appears from 0600 to 1200 hours (Greenwich Civil Time, which

applies to the text below). The highest peak of cluster appearance is 0900 hours. The most vigorous buildup time is between 1200 and 2100 hours; the occurrence frequency at 1800 is the highest. The breakup time is mainly concentrated between 2100 and 0600 hours; however, the most significant breakup is between 0300 to 0600 hours (refer to Fig. 2). These features are the same with respect to diurnal variation of mesoscale convective complexes over the mid-latitudes of the United States[5]. The occurrence of mesoscale cloud clusters over South China is closely to thermal convection as affected by the relief; however, the buildup and breakup of clusters are more closely related to the weather system of the environmental flowfield.

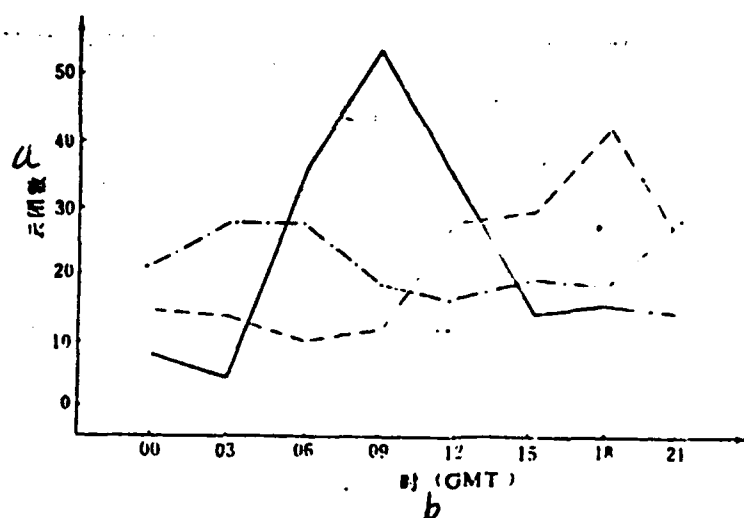


Fig. 2. Time distribution frequency curves of buildup and breakup of cloud clusters over South China (solid line, dashed line, and dot-and-dash line represent, respectively, the occurrence, the highest buildup, and breakup of cloud clusters
KEY: a - Number of cloud clusters b - Hours

III. Formation and Buildup of Mesoscale Convective Cloud Clusters

The process of formation and buildup of mesoscale intensive convective cloud clusters are a very complex problem[6]. Since the last seventies in the United States, several large-scale comprehensive observations and tests were conducted over different areas, thus yielding three interactive processes of convective scale systems in the forming and buildup of intensive convective storms: orographic forcing, intersection of arc-shaped cloud lines, and merging of convective units. Based on available satellite cloud maps and conventional weather data, the authors generalized two main types (west type and east type), by analyzing the developing flowfield and cloud field upon the formation of 176 mesoscale cloud clusters over South China.

West Type (refer to Fig. 3a) is the main form of buildup in the formation of mesoscale cloud clusters over South China; more than one-half of the cloud clusters form in this situation. The southeastward motion of the relatively vigorous cold air masses from the north is hampered by the Nanling Mountain Range; the west section of the cold front gradually stops. The mountain areas of Northwest Guangxi, Northeast Yunnan, and Southwest Guizhou are located in the front lower side of the 500 hPa south branch small trough and the forward side of the stagnant front tail, thus forming a relatively intensive convective zone in the lower atmospheric layer (as shown in the square A zone in the map). Under the thermal convective function in local areas caused by the relief in the afternoons, small but intensive convective cells are formed in the convergent zone; this type of

convective cell gradually builds up with a southeastward motion of the cold front. At the same time, the warm and damp southwesterlies continuously feed the buildup. When these cells move to the left rear fringe of the jet stream core at low altitudes, the divergent air flow from the jet stream core merges with the more intensive southwesterlies to reinforce the low-level convergence of the convective cells. Thus, an eruptive buildup occurs in the cloud clusters (as shown at square B in the map). Later, when the clusters move just below the left rear of the jet stream core, the divergent air flow at low altitudes rapidly weakens the cloud clusters at the sides, or turns to move along a direction slightly to the east. Later, the clusters break up relatively rapidly.

Formation of this type of cloud cluster is abrupt with large area and intensive convection, but its life history is relatively short. Since during the buildup of this type of cloud cluster, the moisture convergence is not very strong, severe weather in the cloud clusters is mainly of short duration, with thunder and gales. Higher rainfalls occur in some local areas.

East type (Fig. 3b) includes three types of cloud cluster formation. The beginning positions of cloud clusters are relatively dispersed. During the buildup, multiple cloud clusters merge. Although the buildup is not as rapid and violent as that of the west type, and the area coverage of the post-merged cloud clusters is not very large, however during the merger, the concentration of large amounts of aqueous vapor and

energy forms intensive convective weather with heavy rainfall. As shown by weather modification experiments conducted abroad, after the merger of two medium-scale cumulonimbus clouds, often a gigantic system of cumulonimbus clouds is formed. The rainfall can be 10 to 20 times greater than the rainfall of two separate clouds[1].

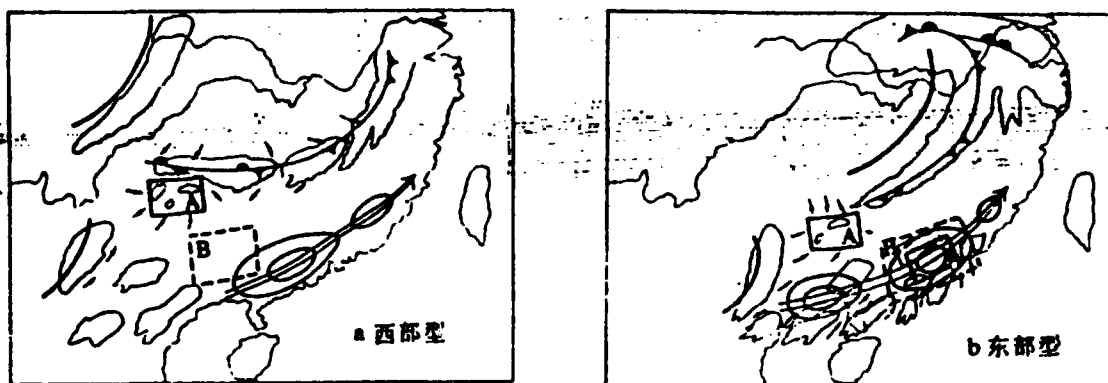


Fig. 3. Simplified map showing the formation and buildup of mesoscale cloud cluster. (a) - West type (b) - East type (boldface curve is 500 hPa trough curve; double solid curves are axial curves for southwesterly jet stream on 800 hPa; bold closed curve shows the gale center on the jet stream axis. Slender short arrows show the low-altitude air flow directions; the front surface is shown conventionally. The light curves show the outlines of cloud area; the solid and the dotted-line squares show, respectively, the regions of beneficial formation and buildup of mesoscale cloud clusters)

In Guangdong and Fujian Provinces, in the eastern part of South China, the process of formation and buildup of the vast majority of mesoscale cloud clusters is of the east type. In this type, the westerly trough at 500 hPa rapidly weakens in its eastward motion. On satellite cloud maps, the tail of the broken point-shaped cloud system gradually weakens and becomes blurred;

however, the convection flowfield there still exists. At the same time, the monsoon small trough gradually approaches, the warm, moist air currents slightly southward at low altitudes and the reduction of the dynamic pressure in front of the trough significantly intensify the convection at the tail end of the point-shaped cloud system, along with the orographic forcing, the residual small convective cells can build up (at square A). This is the first mode of cloud cluster formation of this type. The formation of the second type of cloud clusters is closely related to the lower-altitude jet stream. There is an intensive low-altitude southwesterly jet stream in the central and southern parts of South China; wind speeds at 850 and 700 hPa are 12 to 18 m/s. On the jet stream axis there are frequently two or three gale centers. Surrounding the gale centers, the distribution of the wind field is very uneven, with relatively high nongeostrophic feature, and great variation in divergence, thus providing conditions for forming mesoscale gravity waves, as well as increase and maintenance of local variation values of divergence in the vicinity of the gale center, thus beneficial to the frequent formation of mesoscale cloud clusters at the site (at A of the lower right-hand square in the figure). The third type of cloud cluster is the merger of the sea wind front and active monsoon cloud cluster. These three types of cloud clusters often merge in their relative motion, or two of the three types merge together. During the merger, intensive buildup of cloud clusters takes place. In addition, sometimes these

cloud clusters appear repeatedly in a segment of time, thus causing an area to be affected continuously by a cloud cluster for several times, bringing about persistent rain gush type weather.

IV. Analysis of Typical Examples

1. Intensive buildup of large cloud cluster over Guangxi

On 21 through 22 May 1988, a cloud cluster built up intensively over Guangxi, causing local weather spells of thunderstorms and gales. Rainfall of 20-40 mm accumulated in Central Guangxi, and 50-70 mm of precipitation in local areas of Northwest Guangxi (Fig. 4).

The formation and buildup of this cloud cluster is of the west type. At 0100 hours on the 21st (Fig. 4a), a relatively intensive cold front moved to the north side of Wuyi Mountain of the Nanling Mountain Range; the cold front cloud system was very active. Between 110 and 120 deg. E., the main portion is composed of three convective cloud clusters. The infrared cloud map (EIR) revealed intensification that the bright cloudtop temperature (white bright portion in the cloud map) was as low as -74°C , or even lower. The westernmost cloud cluster covered the largest area with the most active convection. At the tail of the cold front to the west, a small convective cloud cluster (A) showed very distinct boundaries. In the afternoon of the day (21st), as shown in Fig. 4b, the cold front cloud system apparently weakened; the three above-mentioned cloud clusters

merged. The area of the bright cold cloud region inserted into the cloud clusters was reduced; the quasi-circles became banded. The remaining cloud region was basically a medium low cloud system. The convective cell A still existed; its area was somewhat reduced. At about dusk (Fig. 4c), the main body of the cold front cloud system apparently weakened, becoming deteriorated and finally breaking down. The cold cloud front almost disappeared entirely. The residual cloud region consisted mainly of low clouds. In this period, the convective cell A explosively built up into an intensively convective cloud cluster over Northeast Guangxi during the southward movement of the weakened cold front cloud system. The areas of lower-than -74°C cold white bright cloudtop expanded by about fourfold in six hours, from 0600 to 1200 attaining 3×4 square degrees latitude. With later continuous buildup, on the dawn of the 22nd (Fig. 4d), the area again nearly doubled, attaining 5×6 square degrees latitude. At the same time, the weakening and breaking up cold front cloud system again built up into four isolated intensive convective small cloud clusters over the hilly area of Northwest and North Guangdong and Southwest Fujian. The temperature at the bright cloudtop was also low. In the morning of the 22nd, cloud cluster A rapidly weakened; the intensive bright cold convective cloud top broke down; the structure of the cloud cluster loosened. At 0600 hours, the A cloud cluster dissipated, as the process concluded.

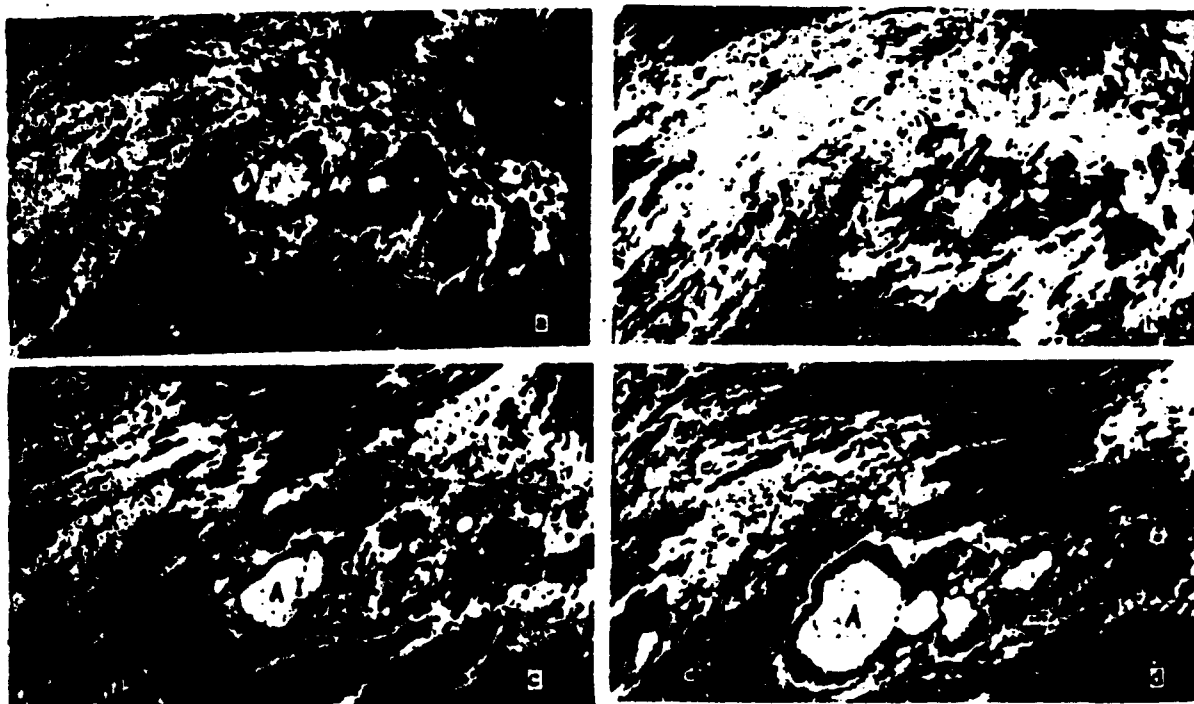


Fig. 4. GMS EIR sequence cloud map of large cloud cluster over Guangxi on 21 through 22 May 1988

(a) - 00Z (b) 06Z (c) 12Z (d) 18Z

Cloud cluster A forms at the forward front surface of the southward-moving cold front tail, and in the ascending zone of mountainous terrain. Later, with the southward movement of the cold front entering the southern and northern parts of Guangxi, on the night of the 21st, explosive buildup appeared. At 1200 on the 21st, the ground surface was the more-intensive large-area convergence field. The divergence value in the vicinity of the cloud cluster center was -2×10^{-5} per second to approximately 4×10^{-5} per second. When the convection stability index $[(T_{850} - T_{500}) + (T_{850} - T_{500})]$ is 44°C , the convection is unstable, thus benefiting the development of convection (Fig. 5).



Fig. 5. Isopleth curves (boldface, dashed curves) for convective instability and ground divergence field (solid curves) in Guangxi and its neighboring area at 12Z on May 21, 1988: divergence unit is 10^{-5} per second

At the same hour on the 500 hPa, the air moisture was high in the vicinity of the cloud cluster center; $T - T_1$ is $0-2^{\circ}\text{C}$. A shear curve at the trend of quasi-southwest to northeast penetrated across the cloud cluster with significant convergence of wind speed; the cloud cluster was in the ascending zone of convergence at the right side of the jet stream inlet of this branch of low-altitude southwesterlies (Fig. 6). In the low altitudes of the convective layer, this warm moist air mass was intensively convergent and ascending because the convection was unstable. This is the beneficial low-altitude condition and the basic cause for the explosive buildup of cloud cluster A. Moreover, in the cloud cluster A buildup, this was basically the sunny zone in the west side and south side of cloud cluster A on the EIR cloud map. There was no input of monsoon cloud cluster and cloud surge into

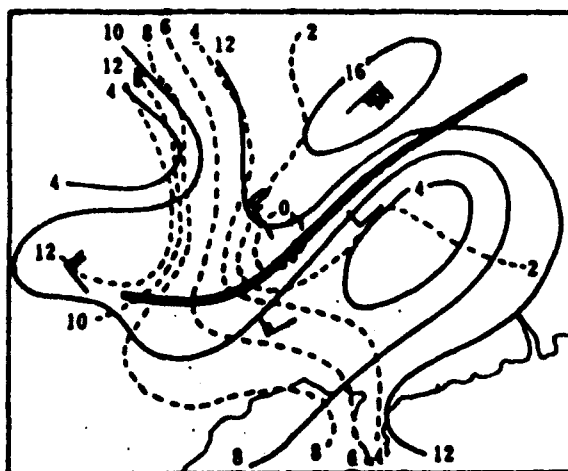


Fig. 6. Map showing comprehensive elements on 850 hPa over Guangxi and its neighboring area at 12Z on May 21, 1988 (light solid curves are the isopleths of wind speed; boldface solid curve is the shear curve; dashed curve is the isopleth curve of $T - T_1$) (unit is $^{\circ}\text{C}$)

the cloud cluster; therefore, the life history was relatively short. At the same time, the accompanying weather was a moving short-duration thunderstorm and gale.

2. Formation, merger, and buildup of multiple cloud clusters over East Guangdong

On 20 through 22 May 1987, there was a continuous formation, merger, and explosive buildup of eight mesoscale intensive convective cloud clusters, consecutively over East Guangdong. In 48 hours, between 1200 hours on the 20th and 1200 hours on the 22nd, over East Guangdong there was rainfall 200-500 mm over large areas. The rainfalls over Haifeng and Lufeng were as high as 800-900 mm, which has been rarely seen historically. The rain gushes caused injuries and fatalities among the population and property losses.

At 1800 hours on the 20th (Fig. 7a), the head portion of the scattered point-shaped cloud system accompanied by the eastward weakening moving cold front moved to the area over the South Yellow Sea and the Northern East China Sea. The tail of the cloud system and the cloud cluster A formed over Central Guangdong moved to South Fujian. At the same time, cloud clusters B and C formed over Central and East Guangdong. Although the areas covered by these cloud clusters were relatively small, convection was relatively active and the bright cloudtop temperature was approximately -70°C , the induced 6-hour rainfall over Northeast Guangdong was 10-25 mm and local rainfall was about 40 mm. Later on, cloud cluster A moved to the Taiwan Straits and weakened and disappeared. During the eastward of cloud clusters B and C, they also gradually weakened. On the west side of cloud cluster B, two small cloud clusters E and F formed; the temperature at the bright cloudtop was lower than -76°C (Fig. 7b). At the same time, outside of the Pearl River estuary, a small cloud cluster G formed. Successively, during the eastward motion of cloud clusters E, F, and G, they merged into a large intensive convective cloud cluster (Fig. 7c, d). Accompanying the formation and merged buildup of these three cloud clusters, the first rainfall peak occurred within two 6-hour periods between 1800 hours on the 20th and 0600 hours on the 21st; there were rainfalls of 20-50 mm in succession over East Guangdong. Local area rainfall was nearly 100 mm. Total rainfall in the 12 hours at Haifeng and Leufeng (reported by

other than the State Weather Forecasting Station) was nearly 500 mm. In addition, in the convergent zone at the tail of the point-shaped cloud system as weakening over the east Sichuan Basin, two cloud clusters D and H formed in succession. With the gradual eastward moving buildup of the point-shaped cloud system, when cloud cluster D moved over the Shaoguan area, the rainfall was 20-50 mm. Between 1800 hours on the 21st and 0100 hours on the 22nd (Fig. 7e,f), cloud cluster D and the three above-mentioned cloud clusters again merged, after weakening. The occasion created another strong cloud cluster buildup; over East Guangdong there appeared the second high rainfall peak. The 12-hour rainfall was 50-100 mm; at Shanwei, the rainfall was 228 mm. Afterwards, this merged cloud cluster moved eastward to the sea and quickly weakened. At the end tail of the weakened point-shaped cloud system, cloud cluster H was formed. After a split, a small convective cell moved eastward to again build up over the eastern Pearl River estuary (Fig. 7g,h) and produced a rainfall of 10-35 mm in East Guangdong. With the eastward movement of the tail of the point-shaped cloud system, the formation of cloud clusters over the land of East Guangdong also terminated.

The activities of the eight above-mentioned continuous cloud clusters occurred over the central and southern portions of South China in a beneficial environment (Fig. 8) at the tail of two consecutive weakening cold fronts passed in forming more stable

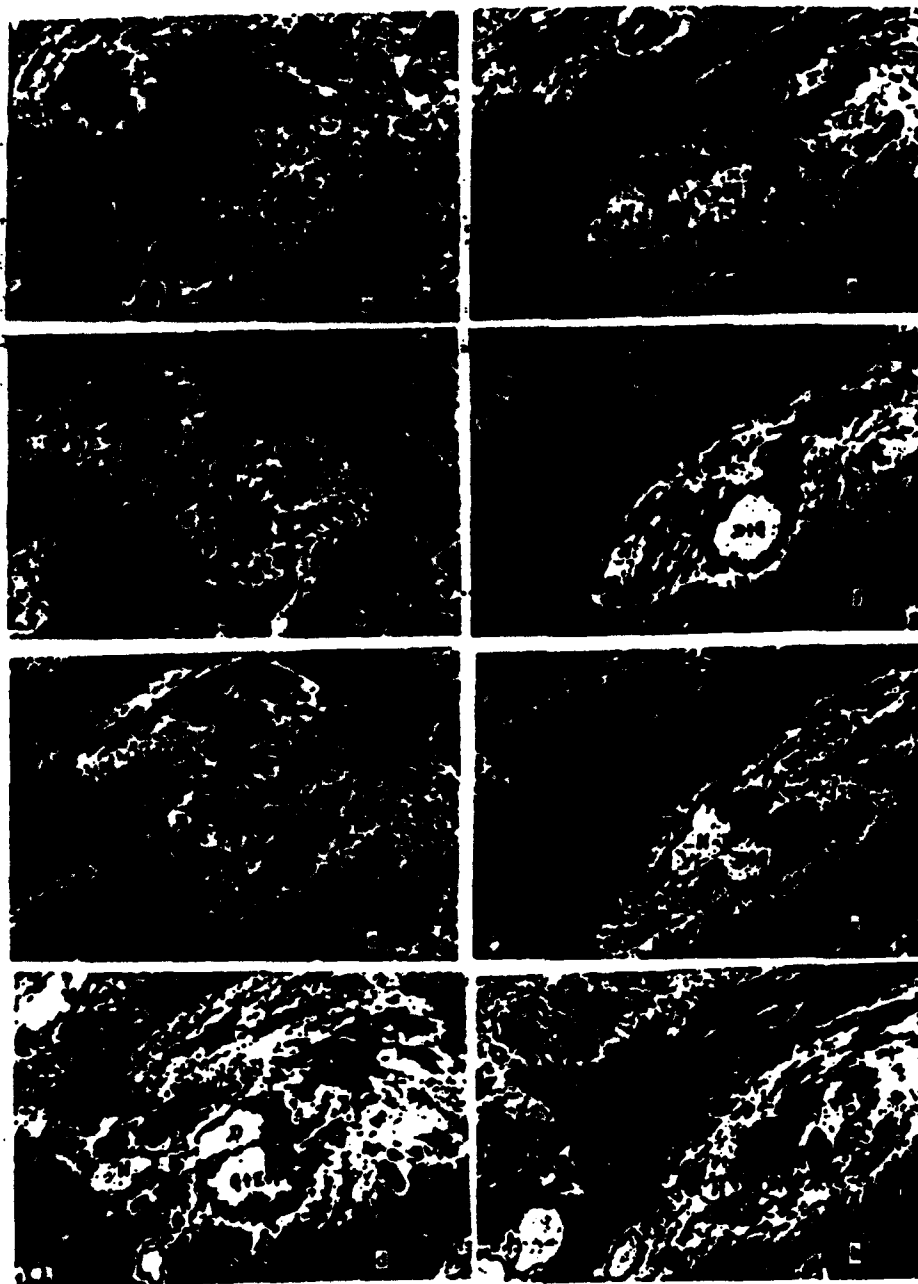


Fig. 7. GMS EIR sequence cloud maps of cloud clusters over East Guangdong between 21st and 22nd May 1987
 (a) 20st, 18Z (b) 21st, 00Z (c) 21st, 06Z
 (d) 21st, 12Z (e) 21st, 18Z (f) 22nd, 00Z
 (g) 22nd, 06Z (h) 22nd, 12Z

low-altitude intensive convection and low-altitude westerly jet stream in maintaining the environment. On the 20th through the 22nd, the trough curves on 800 hPa slowly moved southeastward from the southeastern portion of the southwest area of South China to West Jiangnan [sic]. In the southeast of the trough curve at the low altitude of 12-16 m/s, the southwesterly jet stream axial curve gradually moved southward from the central and northern portions of South China to the coasts of South China. On the axial line of the jet stream, several gale centers of 14-18 m/s moved eastward. In the ground flowfield, the convection curves of the central and southern portions of South China were vigorously active. From the sea surface of the northern portion of the South China Sea, the convective air flow was very intensive. Over the convective curves, there were several large convective centers. With the southward movement of the first cold air mass, the tail (when the cold front weakened and moved eastward) passed the southern portion of South China and changed its characteristics. The remaining convergent curve was situated over the coasts of South China (Fig. 8a). In the vicinity of this convergent curve six cloud clusters (A, B, C, E, F, G) formed in succession together with the merger and buildup of two cloud clusters, causing a high rainfall peak on the 21st. With the eastward movement of the second weak cold air mass coordinated with the above-mentioned long oblique trough, another intensive convergent curve and a low-altitude jet stream again moved southward together from central South China to the coasts.

Although on this convective curve only two cloud clusters D and H were formed, yet they also had two mergers and buildups with the previously mentioned cloud clusters E, F, and G, thus producing the second rainfall high peak on the 22nd.

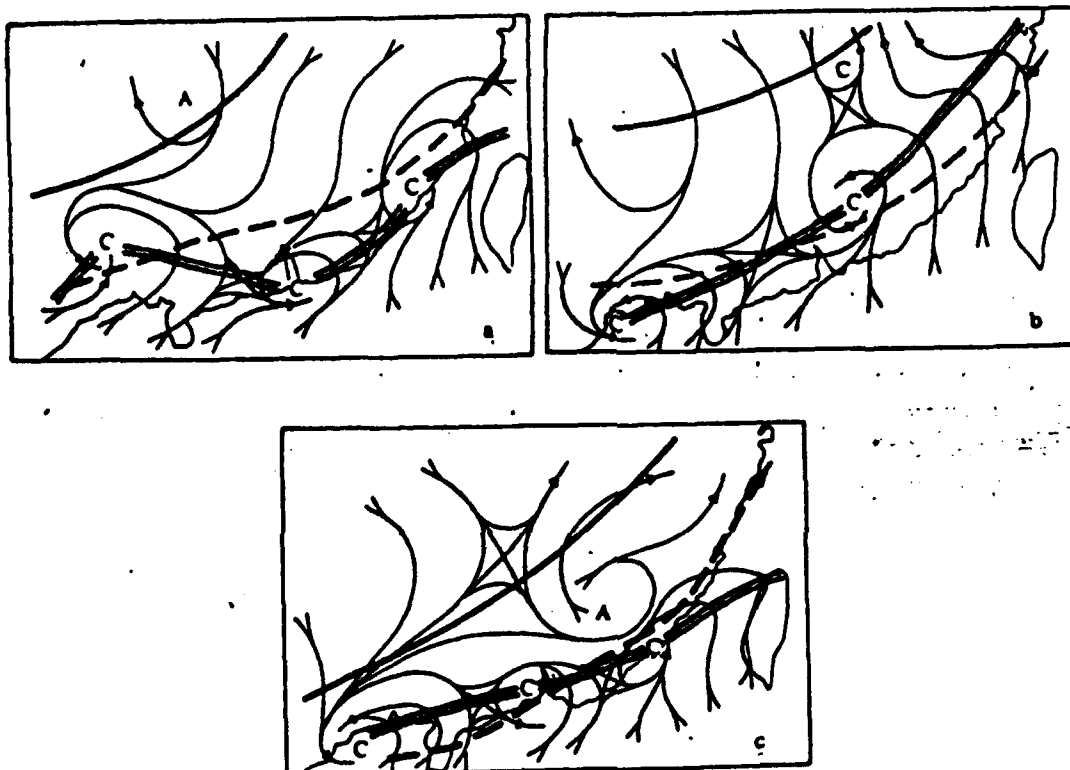


Fig. 8. Low-altitude comprehensive map of convective layer at 00Z on 20 through 22 May 1987 (a) 20nd (b) 21st (c) 22nd (boldface solid curves and dashed [sic] arrows are, respectively, the trough curves on 850 hPa and jet stream axial curves; the streamlines are the ground flowfield; the light parallel curves are convergent curves on the ground map)

V. Conclusions

The article applies satellite data and conventional weather data in making a statistical study of climatic features of

mesoscale convective cloud clusters in South China. By analyzing individual examples, two cloud type models for the formation and buildup of mesoscale cloud clusters are derived. This has practical significance for the further acceptance and upgrading of short-term forecasts of convective cloud clusters in South China. However, mesoscale cloud cluster activity is a research topic of high difficulty. Therefore, the studies reported here are still preliminary. Further deeper study is expected to continue in the future.

The authors are grateful to suggestions from comrade Fang Zongyi and Mr. Tao Shiyan. The first draft of this article was received on August 5, 1989; the final revised draft was received for publication on November 6. The research conducted in the article was funded by the Tropical Scientific Research Foundation of the State Meteorological Administration.

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